CARA Center for Astrophysical Research in Antarctica

Labs from YSI 94 :
Measuring the Speed of Light.

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This is meant to be given to the students.

Part I. Importance of the Speed of Light

Light travels so quickly that it seems to be instantaneous - we are normally not aware that is has a speed at all. Yet, astronomical distances are so enormous that light may take a long time to go from one object - a planet or a star - to another.

For example, it takes 0.12 second for light (or microwaves, or any other kind of *electromagnetic radiation*) to travel from the Earth to a communications satellite in a geosynchronous orbit. The round trip - from Earth and back - for a microwave transmission would be twice this, or 2 x 0.12 second = 0.24 second, which explains why there is a slight delay in some long-distance telephone calls. We can think of this as a distance of 0.24 *light-seconds*.

Light takes 1.28 seconds to travel from the Moon to Earth, and 500 seconds or 8.3 minutes to travel from the Sun to Earth. Since Jupiter is 5.2 times as far from the Sun as the Earth, it takes 5.2 x 8.3 min = 43 min for light to travel from the Sun to Jupiter, and we can say that Jupiter is 43 *light-minutes* from the Sun. Pluto is 39.5 times farther from the Sun than is the Earth; this works out to a distance of 5.5 *light hours*.

These examples give you another way of thinking about the size of the Solar System. (As still another example, stars are typically *light years* apart, not light hours.)

Astronomers thus use time to measure distances, and the scale is based on the speed of light. This is possible because of an important rule:

light always travels at exactly the same speed.

(This is strictly true *in a vacuum*. When light travels through a medium such as air, water, or glass, it goes a bit slower. For all practical purposes, we can ignore this when measuring large distances.)

The other important rule is:

microwaves, radio transmissions, television transmissions, visible light, X-rays, and all other forms of electromagnetic radiation, all travel at exactly the same speed (in a vacuum).

Part II. The General Technique

The speed of something - a car, or a baseball, or a satellite - can be measured if you know the distance traveled and the time to travel that distance. The formula is:

```
                 distance traveled
speed   = -------------------------------.
           time to travel that distance
```

We'll first practice using this equation by calculating the speed of a ball thrown by one student to another. We need to measure the distance between the students, and we need to measure the time-of- flight. If the distance between the students is measured in *feet*, and the time-of-flight is measured in *seconds*, then we will measure the speed in *feet per second*.

Part III. A Ghost Story

Most people who use a TV antenna (as opposed to cable) have noticed that on some stations you see two pictures - the main picture, and another, fainter one that is offset a bit to the right. The fainter one is called a *ghost*. What's happening is this: the antenna is picking up not only the direct signal from the station, but also another signal that has bounced off of a building, mountain, or some other object that can reflect TV signals. The reflected signal will be weaker, but more importantly, it will arrive a bit later, because *it had to travel farther*. Since it arrives later in time, it appears to be offset on the TV set.

To understand why this last statement is true, we need to understand a bit about how a TV set works. A beam of electrons hits a phosphor inside the TV tube, creating a glowing dot. The electron beam is scanned rapidly sideways and down the screen, such that in just 1/30th of a second, the whole screen has been "painted" by 525 scans of the glowing dot, from top to bottom. The scanning is too fast for the eye to see. In the next 1/30th of a second, another picture is painted, and so on, to create something the eye + brain interprets as a moving image.

Since there are 525 scans (also called "lines" or "scan lines"), each one must take only

```
   1              1
--------   =   --------
30 x 525        15,750
```

of a second to travel from the left-hand side of the screen to the right-hand side of the screen.

That means that if a reflected image is offset to the right by one-tenth of the width of the screen, the difference in time between the main image and the ghost must be 157,500th of a second; if the offset is only 1% of the width of the screen, then the difference in time is 1,575,000th of a second, and so on. The point is that a measurement of the offset of the ghost, as a fraction of the width of the screen, gives us a way to measure very small intervals of time.

Part IV. The Ghost from the Yerkes Large Dome

It is often difficult to tell exactly what is causing the reflected signal, since the TV transmission can bounce around a lot before it gets to your antenna. But, if we set up an antenna in the back building and aim it at the large dome, it is reasonable to assume there is only one object that can reflect the transmission, namely the large dome itself. If the antenna also receives a bit of the signal directly from the station, then we will have a main image plus an offset ghost image.

Our antenna, the large dome, and Rockford, Illinois are approximately in a line. That means that if we tune to stations in Rockford, the difference in distance traveled between the main signal and the reflected signal will be simple to calculate - it is just twice the distance from our antenna to the main building. The Rockford stations are:

- channel 13 WREX ABC
- channel 17 WTVO NBC
- channel 23 WIFR CBS
- channel 39 WQRF Fox

Step 1

Turn on the equipment, rotate the dome of the 10-inch telescope to face the main building, and point the antenna towards the large dome. Select any of the different stations listed above and note which gives the best images. Try moving the antenna around to get a good ghost image.

Step 2

With a millimeter scale, measure the offset between the main image and the ghost image, and write that number in the space below.

__________ offset distance between main image and ghost image

Measure the width of the TV screen in millimeters, and write down that number in the space below.

__________ width of the TV screen

Now, what fraction of the width of the screen is the offset of the ghost image?

```
  offset distance
------------------ = ---------------- =
width of TV screen
```

This is equal to the fraction of the width of the screen

Now, finally, what is the delay time for the ghost? That is, by what amount of time did the ghost signal arrive after the main signal?

__________ seconds delay.

Part 3

Measure the distance from the antenna to the large dome, and write the value in the space below.

__________ distance between the antenna and the main building

Now write down the

__________ difference in distance traveled from Rockford to the antenna between the main signal and the reflected signal

Part 4

Good! You have now measured the two quantities needed to determine the speed of light: the distance traveled, and the time to travel that distance. Use the first formula given to calculate the speed of light.

____________ speed of light.

How can you check whether this number is right?

[Hint: the number you wrote down above is probably in feet per second or in meters per second. The number for the speed of light you will find in a textbook is probably in miles per second or in kilometers per second. That means that you will need to do a bit more math in order to compare the two values.]

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PTYS 106 Notes--Units and Conversions

102. Units

When do I use a certain kind of unit?

When you are asked to calculate a certain quantity, you need to make sure you use the correct units. For example, if you are asked to calculate the wavelength of emitted radiation, you want your final answer to have units of length (i.e. nm, μm, mm, m, etc.) If your final answer has units of Hz (frequency) or Kelvin (temperature), then you either made a mistake in your math, used an incorrect equation, or miscalculated your units.

Similarly, if you are asked to find the latitude or longitude of a place on Earth, you want your final answer to have angular units. (i.e. degrees, arc-minutes, arc-seconds) If your final answer has units of time (hours, minutes, seconds), then you probably used the wrong equations.

Below is a chart which compares the units we have seen in this course with the quantity for which each stands.

Type of Unit	Examples	Metric System	English System	Other
length	-distance from Earth to Moon -diameter if the Moon -wavelength -distance of Earth to star	meter, kilometer, nanometer, micrometer, millimeter, Angstrom	foot, yard, mile	Astronomical Units, parsec, light year
time	-period of planet's orbit	seconds (s), minute (min), hour (hr), day (d), year (yr)	same	
speed	-speed of light	m/s, km/s	ft/s, mph	
angles	-altitude to a celestial object -latitude and longitude -angular extent of an object	degree (x), arc-minute ('), arc-second (")	same	
temperature	-temperature of a surface	degrees Celsius, Kelvin	Fahrenheit	
frequency	-frequency of a radio signal	Hertz, MHz	same	
mass	-mass of the Earth	gram, milligram, Kilogram		
power	-power of radiation emitted by a black body	Watt		
unitless	-eccentricity of an ellipse -albedo	no units (just a ratio or a decimal)	same	

Why do we use the metric system?

Converting between units in the metric system is much easier than converting between units in the English system. This is due to the fact that conversions in the metric system are based the number 10, while conversions in the English system are usually (but not always!) based on multiples of the number 12. Try this:

The distance from Tucson to Nogales is roughly 100 km. Remembering that there are 1000 m in a km, calculate the distance from Tucson to Nogales in meters.

100 km x (1000 m/1 km) = 100000 m = 105 m

The distance from Tucson to some random place just outside of Nogales is roughly 60 miles. Remembering that there are 5280 ft in a mile, calculate the distance from Tucson to Nogales in miles.

60 miles x (5280 ft/mile) = 316800 ft

Someone with enough confidence in his or her math can do metric conversions rapidly in his or her head, but the English conversions require a bit more work for most people.

OK, so working with metric can make life simpler. But how do I know whether to multiply or divide by 10, 100, 1000, 10^6, etc.?

You have probably noticed that there is some relationship between a unit's prefix and the basic unit. For example, the prefix for "megahertz" or "MHz" is "mega," which means 1,000,000. Therefore, 1 megahertz would be equal to 1,000,000 Hertz. Below is a list of commonly used metric prefixes.

Prefixes Example

G	Giga	10^9	1,000,000,000	Gyr (gigayear)	10^9 years
M	Mega	10^6	1,000,000	MHz (megahertz)	10^6 Hertz
k	kilo	10^3	1,000	km (kilometer) KHz (kilohertz) kg (kilogram)	10^3 meters 10^3 Hertz 10^3 grams
c	centi	10^{-2}	0.01	cm (centimeter)	10^{-2} meters
m	milli	10^{-3}	0.001	mm (millimeter) mg (milligram)	10^{-3} meters 10^{-3} grams
μ	micro	10^{-6}	0.000001	μm (micrometer)	10^{-6} meters
n	nano	10^{-9}	0.000000001	nm (nanometer)	10^{-9} meters

These prefixes tell us how these units relate to a certain standard unit. For instance, since we know that "k" stands for 1000, we can easily deduce that the terms "kHz" or "kilohertz" refer to 1000 Hz.

(1 kHz = 1000 Hz) Also note that the terms "km" or "kilometer" refer to 1000 m. (1 km = 1000 m)

Similarly, since we know that "m" stands for 0.001, then we can determine that the terms "mg" or "milligram" refer to a mass of 0.001 g. (1 mg = 0.001 g)

How do we convert those other units such as astronomical units and light years?

When we're dealing with very large or very small distances (lengths), we use other units for our convenience. To measure the long distances between planets in the Solar System, we use astronomical units. To measure the greater distances to other stars (other than the Sun!), we use light years or parsecs. To measure the minuscule wavelengths of gamma rays or widths of molecules, we use Angstroms.

Unit	What it is based upon	Conversions
Astronomical Unit (AU)	Average distance of Earth to the Sun	1 AU = $1.495978706 \times 10^{11}$ m ~1.5×10^{11} m
Light year (ly)	Distance light travels in 1 year	1 ly = 6.324×10^4 AU
Parsec (pc)	Distance that corresponds to 1" parallax	1 pc = 3.26 ly
Angstrom (â)	Roughly the width of atoms	1 â = 10^{-10} m 1 â = 0.1 nm

So, suppose that Mars is 0.5 AU from Earth. To find that distance in km, you will have to convert AU to meters, and then from meters to kilometers. (We will use the approximation 1 AU ~ 1.5×10^{11} m for this example.)

0.5 AU x (1.5×10^{11} m / AU) x (1 km / 1000 m) = 7.5×10^7 km

Note that the units AU and m cancel, leaving only units of km. (Recall that you have used the conversions between parsecs, light years, and astronomical units in a homework assignment.)

What about converting temperatures to different scales?

We need to concern ourselves with three temperature scales. First is the Fahrenheit scale, to which we are accustomed as it is used more often than the other scales here in the US. For the most part, the rest of the world uses the Celsius (centigrade) scale. However, scientists usually use the Kelvin scale for reasons which will soon be apparent. In this course, we will mainly use the Kelvin scale. The conversions between these scales are as follows:

Celsius (C) to Fahrenheit (F) : F = 32 + 1.8 C
Kelvin (K) to Celsius (C) : C = K - 273.15

The advantage of the Kelvin scale over the Fahrenheit and Celsius scale is that it is set up so that 0 K = absolute zero, which can be thought of as the coldest possible temperature any object can attain. (The temperature of an object is due to molecular vibrations and collisions in an object. The faster the vibrations, the higher the temperature. If the molecular vibrations were to stop completely, the object would have a temperature of absolute zero. This temperature can never be reached, but we can come close.) For this reason, the Kelvin scale more accurately reflects what occurs in nature than the other scales, so we will use the Kelvin scale in most (if not all!) of our calculations.

Unit Conversion

It is often necessary to convert measurements from one set of units to another. This is done by applying one or more conversion factors. Consider the simple equality:

12 inches = 1 foot

Treating the units as algebraic quantities, divide both sides by foot (or alternatively 12 inches) to produce:

$$\frac{\text{12 inches}}{\text{1 foot}} = \frac{\text{1 foot}}{\text{12 inches}} = 1$$

This is the conversion factor for changing feet to inches (or inches to feet in the alternative case). Any quantity measured in feet that is multiplied by this conversion factor comes out in inches.

- Convert 6.0 feet into inches:

- Convert 6.0 inches into feet:

$$6.0 \text{ inches} \times \frac{1 \text{ foot}}{12 \text{ inches}} = 0.50 \text{ feet}$$

- Convert 55.0 miles per hour into meters per second:

$$55.0 \frac{\text{mi}}{\text{hr}} \times \frac{1 \text{ hr}}{60 \text{ min}} \times \frac{5280 \text{ ft}}{1 \text{ mi}} \times \frac{12 \text{ inches}}{1 \text{ ft}} \times \frac{2.54 \text{ cm}}{1 \text{ inch}} \times \frac{1 \text{ m}}{100 \text{ cm}} = 24.6 \frac{\text{m}}{\text{s}}$$

These conversions employed the following steps:

- Write the original measurement on the left side of the page.
- Multiply the measurement by the first conversion factor that takes you to the desired end result. Make sure that the conversion factor is written such that units cancel! For example, if you want to change a unit in the numerator, write the conversion factor such that the unit is in the denominator of the conversion factor. Treat the units as algebraic quantities and explicitly show where they cancel.
- Continue to write conversion factors until all unwanted units are canceled. In this example, hours were canceled by the first conversion factor leaving units of miles per minute. The minutes unit was canceled by the second conversion factor leaving units of miles per second. Four other conversion factors convert miles to meters leaving the end result in units of meters per second.
- The conversion factors introduced numbers into the original expression. Multiply or divide all numerical factors to get the final converted value. Note that the final result was rounded to 24.6 because the original measurement had three significant figures.

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Astronomical Scales

Grade level: 9-12	Subject: Mathematics	Duration: One to two class periods

Lesson Plan Sections

Objectives | Materials | Procedures | Adaptations | Discussion Questions | Evaluation | Extensions | Suggested Readings | Vocabulary | Academic Standards | Credit

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Objectives

Students will

1. understand how scaling factors can be used to make representations of astronomical distances;
2. learn how to write and solve equations that relate real distance measurements to scaled representations of the distances; and
3. understand how the use of scientific notation makes calculations involving large numbers easier to manage.

Materials

The class will need the following:

- Calculators
- Pencils and paper
- Ruler
- Reference materials about the universe, such as books, magazines, and the Internet
- Copies of Classroom Activity Sheet: Understanding Sizes and Distances in the Universe
- Copies of Take-Home Activity Sheet: Comparing the Sizes of Planets

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Space: Distance and Time

Teaching Tools

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1. Begin by discussing the vastness of the universe. For example, tell students that light travels at the unimaginably fast speed of 300 million meters per second, and yet light takes years to travel to us from the stars and takes thousands or even *millions* of years to travel the depths of space between galaxies. When we're dealing with those kinds of distances, it's no wonder that we often think of them as being beyond our grasp. One way to put these distances into perspective is to think of them as multiples of smaller-scale distances. By putting these quantities in the context of a well-understood frame of reference, they begin to have more meaning.
2. Help students grasp our place in the enormous universe by reviewing your school's "galactic address"—beginning with its street address and ending with its place in the universe. Discuss the different units of measurement that are used to describe distances in each part of the galactic address. Give students examples for each step, or have them use reference materials to provide their own examples. Review any unfamiliar units of measurement, such as light-years and astronomical units. By thinking about their location on a small scale first and then moving out to a much larger scale, students begin to get a sense of how distance is measured at each scale.

Place	**Units of measurement**	**Example**
Street address	Feet, meters (within a house)	A room might be 10 × 14 feet.
City	Miles, fractions of miles	You might drive ½ mile to the grocery store; a town might be about 10 miles wide.
State	Tens to hundreds of miles	The distance from Austin to San Antonio is a little more than 50 miles; Texas is about 600 miles across.
United States	Hundreds to thousands of miles	The distance from New York to Los Angeles is 3,000 miles.
Earth	Tens of thousands of miles.	Earth's circumference is 25,000 miles.

Solar System	Millions to billions of miles, or astronomical units (AU). (An AU is the average distance from Earth to the sun, or 93 million miles.)	Neptune is 30 AU, or 2.79 trillion miles, from the sun.
Milky Way Galaxy	Hundreds of thousands of light-years. (A light-year is the distance that light travels in one year, or about 6 trillion miles.)	The Milky Way is about 100,000 light-years across.
Local Group (a cluster of about 20 galaxies, including the Milky Way)	Millions of light-years	The Andromeda galaxy is about 2.2 million light-years away from our Milky Way galaxy.
Supercluster (a group of clusters)	Hundreds of millions of light-years	The Virgo supercluster of galaxies is about 150 million light-years across.
Universe	Billions of light-years	The farthest known galaxy (the edge of the observable universe) is 13 billion light-years away.

3. Explain that one way to put the enormous sizes and distances of space into perspective is to compare them to smaller scales that are easier to grasp. In this activity, students will convert distances and sizes in space to smaller units. To begin, distribute the Classroom Activity Sheet: Understanding Sizes and Distances in the Universe, and have students work in pairs to answer the questions.
4. To help students understand how to solve these problems, you may wish to do the following problem together as a class:

   Problem: Using a scale in which a quarter represents Earth, what would the distance from Earth to the moon

be?

Solution: Three pieces of information are needed in order to determine this scale distance to the moon: the diameter of the quarter, Earth's diameter, and the actual distance from Earth to the moon. Measuring the quarter reveals that it has a diameter of 1 inch. Earth's diameter is about 8,000 miles. The actual distance from Earth to the moon is an average of 240,000 miles, although this distance can vary with the moon's orbit around Earth. For these calculations, though, the average can be used. Now that we have these three pieces of information, we can find the fourth piece (the scale distance *d*) by setting up the following ratio:

$$\frac{\text{a diameter of quarter}}{\text{diameter of Earth}} = \frac{\text{scale distance (d)}}{\text{average Earth-moon distance}}$$

This is equivalent to the statement "The diameter of a quarter is to Earth's diameter as our scale distance is to the actual average Earth-moon distance."

Substituting what we know shows us that:

$$\frac{\text{1 inch}}{\text{8,000 miles}} = \frac{d}{\text{240,000 miles}}$$

Remember that it's important to keep track of the units. If Earth's diameter had been given in kilometers, it would be incorrect to use 240,000 miles for the Earth-moon distance. We would need to convert that distance to kilometers, too. Because both diameters are given in miles, they cancel each other and can be crossed out of the equation. In this problem, we should expect our result to be in inches, the same unit as the quarter's diameter. By multiplying both sides of the equation by 240,000 miles to isolate *d*, we find that

d = (240,000 miles) × (1 inch/8,000 miles) = 30 inches

So, at this scale, the distance between Earth and the moon would be 30 inches.

5. Before students start working on the problems, it may be useful to go over scientific notation, which is a helpful way to deal with large numbers. Use the following examples to illustrate the powers of 10:

- 1 can be written as 10^0 (because anything to the power zero is 1).
- 10 can be written as 10^1 (because anything to the first power is itself).
- 100 can be written as 10^2 (because 10 multiplied by itself, or 10 × 10, equals 100).
- 1,000 can be written as 10^3 (because 10 multiplied

three times, or 10 × 10 × 10, equals 1,000).

Explain that we can use these powers of 10 to represent decimal places, too:

- 3.4 can be written as 3.4×10^0.
- 99.1 can be written as 9.9×10^1.
- 4,526 can be written as 4.526×10^3.

Review the properties of exponents to make scientific notation even more useful:

- When multiplying two numbers with exponents, if the base numbers are the same, just add the exponents. For example, $10^5 \times 10^3 = 10^8$.
- When dividing two numbers with exponents, if the base numbers are the same, subtract the exponents. For example, $10^4/10^2 = 10^2$.

6. Have each pair of students solve the problems listed below, which also appear on the Classroom Activity Sheet: Understanding Sizes and Distances in the Universe. Also included for students are constants that provide helpful information to be used in scaling. Students must figure out which information is needed to solve each problem. Students can work with partners to solve the problems, but each student should fill out his or her own sheet. All the questions from the Classroom Activity Sheet and the answers are listed below. Questions on the Classroom Activity Sheet: Understanding Sizes and Distances in the Universe

   If Earth were the size of a penny

   a. how large would the sun be? *(81 inches, or 6.7 feet, in diameter)*
   b. how far away would the sun be? *(8718.75 inches, 726.5 feet, 242 yards)*
   c. What is located about that distance from your classroom? *(Answers will vary.)*

   If the sun were the size of a basketball

   - how far away would Neptune be from the sun? *(3237 feet, or 0.6 miles)*
   - how far away would the nearest star, Proxima Centauri, be from the sun? *(5,538 miles)*
   - Find two places on a world map that are about this distance apart. *(Answers will vary.)*
   - how far would it be to the center of the Milky Way? *(36,538,218 miles)*
   - About how many trips to the moon does this distance equal? *(152)*

   If the Milky Way were the size of a football field

- how far away would the Andromeda galaxy be? *(6,600 feet, or 1.25 miles)*
- how far would it be to the farthest known galaxy? *(39 million feet, or 7,386 miles)*
- Find two places on a world map that are about this distance apart. *(Answers will vary.)*

Helpful Measurements

- A penny is about ¾ inch in diameter.
- Earth is 8,000 miles across.
- The sun has a diameter of 861,000 miles.
- One mile equals 5,280 feet.
- The average distance from Earth to the sun is 93 million miles.
- A basketball is roughly 12 inches in diameter.
- Neptune is 30 AU from the sun, or 2.79 trillion miles.
- One light-year is 6 trillion miles.
- The nearest star, Proxima Centauri, is 4.2 light-years away.
- The sun's distance from the center of the Milky Way is about 30,000 light-years.
- A football field is 100 yards (300 feet) long.
- The Milky Way is about 100,000 light-years across.
- The distance to the Andromeda galaxy is 2.2×10^6 light-years.
- The farthest known galaxy is 13 billion light-years away.

7. Assign the Take-Home Activity Sheet: Comparing the Sizes of Planets for homework. If time permits, discuss the answers in class. You could have students draw the planets to scale to compare the sizes of different planets visually.

Back to Top

Adaptations

Complete the Classroom Activity Sheet as a whole-class project. Instead of completing all seven problems focus on four or five. Students may also enjoy completing the Take-Home Activity Sheet together as a class.

Back to Top

Discussion Questions

1. Parallax is the apparent change in position of an object when it's viewed from two different places. Astronomers use this phenomenon to measure the distances to some stars. They assume that the stars are fixed, and as the Earth moves in orbit they take measurements of the apparent shift in position. Then they calculate the distance based on a trigonometric relationship between the parallax angle and the "baseline" (the radius of Earth's orbit). Considering that the more distant an object is, the smaller the angle it will make, why would parallax measurements be better suited for stars than for galaxies?
2. What is the value of using exponents? Give some examples of when they are commonly used. *(Exponents are used to express and calculate large numbers. For example, if you needed to multiply 1,000,000,000,000,000 by 1,000,000,000, instead of dealing with all those zeros, you could write the equation as 10^{15} X 10^{9} and add the exponents to get the answer, 10^{24}. Exponents are also used in business to express large sums of money and in science to express pH levels, the magnitude of earthquakes, and the brightness of stars.)*
3. Vast distances in space are often measured in light-years. A light-year is the distance that light travels in one year, or about 6 trillion miles. Altair, a star in the constellation Aquila, is 16.6 light-years away, which means that the light we see now from that star left its surface 16 years and 219 days ago. Describe what was happening in the world when the light we are seeing from Altair first left that star. How far away is Altair in miles?
4. Explain why it would be impossible for scientists to measure stellar distances that are accurate to within a few feet. Why is it not critical to attain such accuracy when dealing with astronomical distances?
5. Does knowing how to use a scale on a map help you understand how to use scale to measure distances in the universe? How are they similar? How are they different?
6. Describe how you could measure the height of a mountain without having to climb it. (Hint: Imagine that you're standing 10 miles from the base of the mountain.)

Back to Top

Evaluation

You can evaluate students using the following three-point rubric:

- **Three p ints:** active participation in classroom discussions; cooperative work within groups to complete the Classroom Activity Sheet; ability to answer more than three questions correctly
- **Two points:** some degree of participation in classroom discussions; somewhat cooperative work within groups to complete the Classroom Activity Sheet; ability to answer three questions correctly
- **One point:** small amount of participation in classroom discussions; attempt to work cooperatively to complete the Classroom Activity Sheet; ability to solve one problem correctly

Back to Top

Extensions

How Many Miles Are There in a Light -Year?
Tell students that we know that light travels at a speed of 186,000 miles per second. Have them use that information to figure out how many miles are in a light-year. Then have them try to figure out a scaling factor to help make the large distance easier to understand.

Answer: Multiply the speed of light by the length of time in one year. The tricky part, however, is that the speed of light is expressed in miles per second. Because you have to keep the units the same, you must figure out the length of time in one year in seconds. To do that, multiply the number of days in one year (365) times the number of hours in one day (24) times the number of minutes in one hour (60) times the number of seconds in one minute (60). The answer is 31,536,000 seconds. To find out how many miles are in a light-year, multiply 186,000 miles per second by 31,536,000 seconds. The answer is about 6 trillion miles. To understand what this means, think of Earth, which has a diameter of 8,000 miles, as being the size of a pea, which has a diameter of ¼ inch. Using that scale, a light-year would be about the distance across the United States.

Selecting the Right Units
Explain to students that establishing the most appropriate unit of measurement is critical when it comes to measuring distances. The right choice of unit can make calculations simpler and help ensure accuracy. Have them imagine trying to measure a mountain in centimeters or an ant in miles. Ask students to research the items in the list below and arrange them in order of scale from smallest to largest. Then have them write down, next to each item, the unit best suited for measuring it. When the list is complete, have the class discuss the tools and procedures that could be used to make each measurement.

- an electron
- the Olympus Mons (a volcano on Mars)
- the Amazon River

- the Great Red Spot (a hurricanelike feature in Jupiter's atmosphere)
- a #2 pencil
- Mt. Everest
- a school flagpole
- the Ring Nebula (estimated to be ½ light-year across)
- an EP-3E reconnaissance plane
- Ganymede (the largest moon of Jupiter)
- the Empire State Building
- a grain of wild rice

Back to Top

Suggested Reading

The Astronomy Café: 365 Questions and Answers from "Ask the Astronomer"
Sten Odenwald. W. H. Freeman, 1998.
Using a question-and-answer format, the author covers a wide range of information about space. Each chapter is preceded by a short description of the questions most people have about astronomy. Many questions relate to the distances between the stars and planets and their relative sizes. A few color plates, along with charts and graphs, add to the text.

Milestones of Science
Curt Suple. National Geographic, 2000.
Filled with the luscious photographs that are National Geographic's trademark, this title traces the history of science from prehistory to the present. Each chapter covers a particular time span and the development of man's understanding of the universe. Especially exciting are the chapters that cover the development of modern astronomy, from Galileo to today's space flights.

Back to Top

Vocabulary

astr nomical unit
Definition: A unit of length used in astronomy equal to the mean distance of Earth from the sun, or about 93 million miles (150 million kilometers).
C ntext: In expressing planetary distances, multiples of the castronomical unit—the average distance from Earth to the sun—are often used.

light-year
Definition: A unit of length in astronomy equal to the distance that light travels in one year in a vacuum, or about 5.88 trillion miles (9.46 trillion kilometers).
Context: Many astronomers prefer to use **light-years** to measure stellar distances because they are easier to work with than other units.

parallax
Definition: The angular difference in the direction of a celestial body as measured from two points in Earth's orbit.
Context: After measuring the star's **parallax**, astronomers were able to determine that the star was much closer than previously thought.

scaling factor
Definition: The proportion between two sets of dimensions.
Context: The map indicated a **scaling factor** of 1 inch to every 10 miles.

Back to Top

Academic Standards

This lesson plan may be used to address the academic standards listed below. These standards are drawn from Content Knowledge: A Compendium of Standards and Benchmarks for K-12 Education: 2nd Edition and have been provided courtesy of the Mid-continent Research for Education and Learning in Aurora, Colorado.

Grade level: 9-12
Subject area: Mathematics
Standard:
Understands and applies basic and advanced properties of the concepts of numbers.
Benchmarks:
Understands the properties and basic theorems of roots, exponents (e.g., $[b^m][b^n] = b^{m+n}$), and logarithms.

Grade level: 9-12
Subject area: Mathematics
Standard:
Understands and applies basic and advanced properties of the concepts of measurement.
Benchmarks:
Selects and uses an appropriate direct or indirect method of measurement in a given situation (e.g., uses properties of similar triangles to measure indirectly the height of an inaccessible object).

Grade level: 9-12
Subject area: Mathematics
Standard:
Understands and applies basic and advanced properties of the concepts of measurement.
Benchmarks:
Uses unit analysis to solve problems involving measurement and unit conversion (e.g., between the metric and U.S. customary systems and in foreign currency conversions).

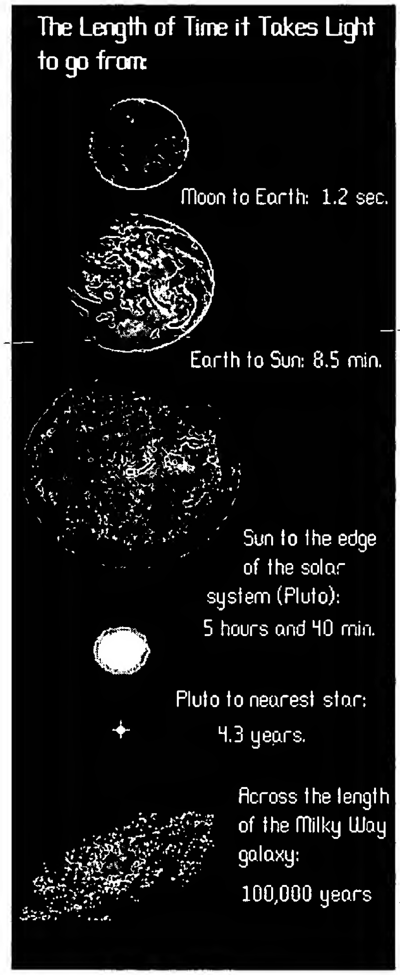
Back to Top

Credit

Chuck Crabtree, freelance curriculum writer.

Back to Top

The Speed of [redacted]



Light travels at a speed of 186,000 miles a second or 700 million miles an hour. For scale, the distance from the Earth to the Moon is about 239,000 miles. This seems pretty fast and indeed theory says that nothing can travel faster than the speed of light.

In our every day lives light seems to travel from one place to another instantaneously. When we flip on the light in a room there is no delay between when we first see the bulb start glowing and when light illuminates the far corners of the chamber. Our nervous systems are much too slow to notice the rays of light that appear from the bulb and move like a wave washing over the room.

When we deal with the immense distances of space, though, even light seems slow. When astronauts were on the Moon it took over a second for the radio waves (which travel at the speed of light) carrying their voices to reach us. Light coming from the sun takes eight and one half minutes to hit Earth. (This means that if the sun were suddenly to go dark, it would take over eight minute for us to notice) Light from the nearest stars, other than the sun, takes four and a half years to get here. From the farthest stars in distant galaxies it can take billions of years for the light to arrive..

The distance light can travel in a year is called a "light year." The light year is one of the basic measures of distance for astronomy.

When designing probes for trips to other planets in our solar system it is important for the planners to keep the communications time lag, caused by the speed of light, in mind. For example, a probe designed to land on Mars must be smart enough to handle problems in the flight on it's own without instructions from Earth. If a course change is needed during landing the probe would have to do it automatically. The delay

caused by the probe requesting instructions from Earth and getting commands back might be nearly an hour, plenty of time for the probe to crash.

The delay caused by the speed of light can sometimes be noticed here on Earth during telephone calls. Long distance calls that have been routed over one or more space satellites may cause a half second or so delay between the speaker and the listener.

The speed of light has several properties which may seem counter-intuitive to us, but are true:

-Nothing travels faster than the speed of light.

-No matter how fast you are moving the speed of light seems to be the same speed as if you were not moving at all.

-As an object or person is accelerated toward the speed of light time slows down for it/him.

This last property leads to the "twins" effect: Twin brothers live on Earth. One brother takes a trip to a distant star traveling at a high percentage of the speed of light. When the twin returns he will be younger than his brother because for him time slowed down during the trip.

This effect, called "time dilation," helps explain why the speed of light is the same no matter how fast you are going. As a traveler accelerates time slows down for him. This, in turn, affects his measurements.